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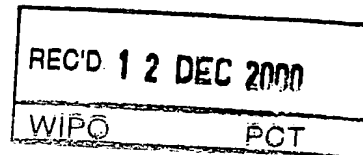


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PROVISIONAL SPECIFICATION FOR THE INVENTION ENTITLED:

Process for Recovering Energy From Carbon-Containing Materials

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This invention is best described in the following statement:

Process for Recovering Energy from Carbon-Containing Materials

Technical Field

The invention relates to processes for converting carbon-containing materials, in particular waste materials containing organic substances, into combustible fuels and thereby recovering energy from the carbon-containing materials.

Background of the Invention

The disposal of ever-increasing quantities of waste materials is a significant challenge in many parts of the world and is becoming a more significant problem as the world's population becomes increasingly urbanised. Furthermore, the increasing human population and increasing levels of affluence are resulting in larger quantities of waste materials of various kinds being generated. Disposal strategies currently utilised for dealing with wastes include landfill, biological degradation by various means, combustion, and various chemical treatment processes. However, each of these methods suffers from one or more disadvantages. For example, existing disposal methods may cause pollution, may be energy intensive, or may be wasteful of limited resources such as land. Additionally, many waste materials constitute a source of useful energy if efficient means of recovery of that energy can be devised. For example, waste incineration is an effective way of decreasing the bulk of waste material for disposal, but typically the heat generated by the incineration is not recovered, and in addition the process can lead to the generation of pollutants such as nitrogen oxides and dioxins, and the generation of large quantities of greenhouse gases. Hence there is a need for improved waste treatment or disposal processes which are environmentally benign and which result in the recovery of useful energy from the wastes.

It is an object of the present invention to provide an efficient method for the recovery of useful energy from carbon-containing materials, and simultaneously to provide an environmentally acceptable way of disposing of waste materials with minimal adverse environmental impact.

Summary of the Invention

In a first embodiment of the invention there is provided a process for generating heat from a carbon-containing material which includes the steps of:

(a) pyrolysing said material in a pyrolysis zone of a reactor at an elevated temperature to produce a carbon-enriched solid and a combustible gaseous product;

(b) burning a first part of said gaseous product to produce a first gaseous combustion product and to heat said pyrolysis zone so as to maintain said elevated temperature;

(c) removing a second part of said combustible gaseous product from said reactor;

(d) burning said second part of said combustible gaseous product to generate heat and produce second gaseous combustion products; and

(e) returning said first and second gaseous combustion products to said pyrolysis zone.

5 Thus, the process of the first embodiment provides a process whereby useful energy may be recovered from a carbon-containing material, but which produces substantially no gaseous emissions, since substantially all of the gaseous products produced in the process are returned to the process after they have been burned.

10 In one form of the process of the first embodiment of the invention, the carbon-enriched solid may be contacted with steam at a temperature at which the water gas reaction occurs, so as to produce therefrom a mixture containing hydrogen and carbon monoxide.

Thus, in a second embodiment of the invention there is provided a process for generating heat from a carbon-containing material which includes the steps of:

15 (a) pyrolysing said material in a pyrolysis zone at a first elevated temperature to produce a carbon-enriched solid and a first combustible gaseous product;

(a') transferring said carbon-enriched solid and said first combustible gaseous product to a reaction zone;

20 (b) reacting said carbon-enriched solid with water vapour in said reaction zone at a second elevated temperature to produce a second combustible gaseous product containing hydrogen gas and carbon monoxide;

(c) burning a first part of said second combustible gaseous product to produce first gaseous combustion products and to heat at least said reaction zone so as to maintain said second elevated temperature;

25 (d) removing a second part of said second combustible gaseous product from said reaction zone;

(e) burning said second part of said second combustible gaseous product to generate heat and second gaseous combustion products; and

(f) returning said first and second gaseous combustion products to said pyrolysis zone.

30 In a further form of the process of the invention, a part of combustible gaseous products produced by pyrolysis of the carbon-containing material, and/or produced by reaction of water vapour with the carbon-enriched solid, are removed from the reactor as a combustible gaseous fuel which may be transported if desired to a location remote from the reactor and from which energy may be recovered by any convenient method.

Therefore, a third embodiment the invention provides a process for converting a carbon-containing material to a combustible gaseous fuel which includes the steps of:

(a) pyrolysing said material in a pyrolysis zone at a first elevated temperature to produce a carbon-enriched solid and a first gaseous product;

(b) reacting said carbon-enriched solid with water vapour in a second reaction zone at a second elevated temperature to produce a second gaseous product containing hydrogen gas and carbon monoxide;

(c) burning a first part of (i) said first gaseous product, (ii) said second gaseous product or (iii) a mixture thereof so as to heat at least said reaction zone and maintain said second elevated temperature; and

(d) removing the remainder of said first and second gaseous products as said combustible gaseous fuel.

In a fourth embodiment of the invention there is provided a system for recovering energy from carbon-containing material, the system including:

a reactor vessel equipped with heating means to heat the vessel;

means to admit said carbon-containing material to the vessel;

gas offtake means operatively associated with the reactor vessel to permit gases generated in the vessel to be removed therefrom;

a first gas conduit between said gas offtake means and said heating means to transfer a first part of said gases generated in said vessel to said heating means;

ignition means adapted to ignite said gases in said heating means; and

energy recovery means operatively associated with the gas offtake means for recovery of energy from a second part of said gases generated in said vessel.

The energy recovery means typically includes a high pressure boiler wherein the second part of the gases generated in the reactor vessel is burnt. More typically, the system further includes a second gas conduit adapted to transfer gas combustion products from the energy recovery means to the reactor vessel.

Brief Description of the Drawings

Figure 1 is a schematic representation of a system for recovery of energy from waste materials utilising a process in accordance with the third embodiment of the present invention.

Figure 2 is a schematic representation of a system for recovery of energy from waste materials utilising a process in accordance with the second embodiment of the present invention.

Figure 3 is a diagram of a suitable reactor for carrying out a process in accordance with the invention.

Figure 4 is a diagrammatic representation of a reactor used in laboratory scale trials of a process according to the invention.

Figure 5 is a schematic representation of a system used in laboratory scale trials of a process according to the invention.

Detailed Description of the Invention

In the processes of the invention, the carbon-containing material usually contains carbon in chemically bound form, and may contain other elements. Usually, the material additionally contains the element hydrogen in chemically bound form. It may also contain oxygen and/or other elements. The material is typically a waste material, but it need not be. Thus, materials for use in the process of the invention may also include conventional solid fuels such as coal, coke, anthracite, bituminous coal, peat etc, or other materials such as timber, paper, cardboard, etc. However, advantageously the carbon-containing material is a waste material, which may be any organic waste such as sewage; municipal solid waste; agricultural waste of various kinds including wood waste, bagasse, rice hulls, prunings, abattoir waste and manure; industrial wastes of various kinds including pulping liquor from paper pulp mills, solids and sludges from waste water treatment, plastics, coal washing solids, shale, spent solvents, oil refinery wastes, contaminated soils, car tyres and so on. The composition of the waste is not critical to the process of the present invention, nor is its moisture content. However, typically the waste will have been processed in a preliminary step to remove gross quantities of water, where present, by one or more methods which are generally known in the art for that purpose such as centrifuging, filtering, skimming, evaporation, etc.

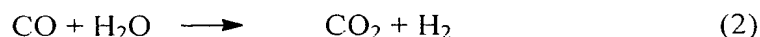
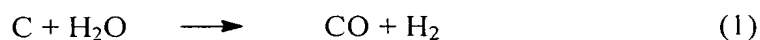
The pyrolysis reaction in the processes of the present invention typically occurs at a temperature in the range of about 200°C to 600°C, more typically in the range 200°C to 400°C. Generally, in the processes of the second and third embodiments the pyrolysis reaction occurs in the same reactor as reaction step (b) but it can occur in a separate reactor. A substantially oxygen-free atmosphere is typically generated in the pyrolysis zone by conducting the pyrolysis in a closed vessel so that any oxygen which the vessel contained initially is consumed by reaction with the carbon-containing material, or with elemental carbon, at the temperature of the pyrolysis zone. Alternatively the pyrolysis reaction zone may be initially purged with an oxygen-free gas, such as nitrogen, carbon dioxide, steam or mixtures thereof. For example, in the processes of the second and third embodiments a part

of the gaseous product generated in reaction step (b) may be passed from the reaction zone for step (b) into the pyrolysis reaction zone so as to sweep out oxygen.

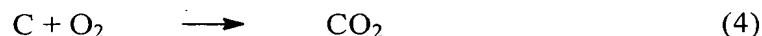
The pyrolysis reaction results in coking or charring of the carbon-containing material to produce a carbon-enriched solid material and simultaneously generates low molecular weight organic substances which typically vaporise at the temperature of the pyrolysis reaction. Water vapour is also typically liberated as steam by the pyrolysis process, unless the carbon-containing material is dry and the carbon-containing substances present are mainly hydrocarbons (for example used car tyres). In the latter case, it will be necessary to add steam or water to the reaction zone in the processes of the second and third embodiments.

The pyrolysis reaction produces a carbon-enriched solid material and a vapour phase. Optionally, the vapour phase may be cooled to liquefy any condensable materials which it contains before the remaining gas, or part of it, is sent either to the reaction zone for step (b) (in the processes of the second and third embodiments) or for burning (in the process of the first embodiment). However usually the vapour phase is directed to its destination without cooling and condensation. Alternatively, in the processes of the second and third embodiments the vapour phase may be taken off from the pyrolysis zone and exploited for its energy content in any convenient way. In that case, it will be necessary to provide water or steam to the reaction zone.

In step (b) of the processes of the second and third embodiments the carbon-enriched solid from the pyrolysis step is contacted with steam in a reaction zone at a second elevated temperature, thereby undergoing a water gas reaction to produce a gaseous mixture containing hydrogen and carbon monoxide. Some carbon dioxide may be produced in this reaction also. Typically, a mixture of carbon monoxide and carbon dioxide is generated, but it will be appreciated that the relative proportions of carbon monoxide and carbon dioxide depend on the ratio of steam to carbon in the reaction zone, on the temperature of operation and on the concentration of oxides of carbon already present. Chemical reactions occurring in the reaction zone may be represented schematically as follows:



Additionally, if any oxygen is present in the reaction zone, the following reactions can occur:



Hence, if sufficient steam is available and carbon monoxide is removed from the reaction zone, carbon in the carbon-enriched solid tends to be consumed and converted into oxides of carbon. Further charring/coking of the carbon-enriched solid may also occur in the reaction zone. Advantageously, however, carbon monoxide is permitted to accumulate
5 in the reactor by recycling to the reactor all combustion products after burning the first and second gaseous products, as in the process of the second embodiment.

Typically, the water vapour or steam for the reactions in the reaction zone is provided by the vapour phase from the pyrolysis reaction. However, depending on the water content of the carbon-containing material originally, or for other operational reasons, it may be
10 necessary or desirable to utilise an external source of water or steam for use in step (b).

The second elevated temperature is typically a temperature in the range of about 200° and upwards. The temperature is, however, usually to the lower end of this range, typically about 315°C to about 480°C, for reasons of energy conservation and to lower the strength of the ash produced from the carbon-containing material by the processes of the invention.
15 High ash strengths can lead to difficulties with ash removal from the reactor.

Since at least reaction (1) and forward reaction (3) above are endothermic, an external source of heating must be provided to the reaction zone in order to maintain the reaction. Except when the process of the invention is first started up, the heat necessary to sustain step (b) in the processes of the second and third embodiments is provided by burning a part
20 of the water gas generated in step (b) and/or a part of the gaseous product generated in the pyrolysis step. More typically, substantially all of the gaseous product generated in the pyrolysis step is passed to the reaction zone for step (b), and hence the gaseous product containing hydrogen and oxides of carbon generated by step (b) is mixed with gaseous products obtained during the pyrolysis step. It will be appreciated, however, that low
25 molecular weight organic substances generated during the pyrolysis step may undergo further reactions under the conditions of the water gas reaction in step (b).

In the process of the first embodiment typically about 30% of the gaseous materials generated in the pyrolysis zone is burnt to provide the heat necessary to maintain the elevated temperature in the pyrolysis zone. Similarly, in the in the processes of the second
30 and third embodiments typically about 30% of the gaseous materials generated in steps (a) and (b) zone is burnt to provide the heat necessary to sustain the reactions in step (b). However, it will be appreciated that in all cases the quantity of gaseous product required to be combusted for these purposes will depend on the carbon content of the carbon-containing material used, its water content and other components present.

From the foregoing it will be seen that typically approximately 70% of the gaseous product generated in the processes of the invention is available for removal from the reactor and constitutes a useful fuel. For example, the gaseous products removed from the reactor may be burnt in a high pressure boiler so as to raise steam for the generation of electricity, or for any other conventional purpose.

The portion of the gaseous product which is burnt to maintain the temperature(s) in the reactor may be combusted in air, and the resulting heat applied externally to the reactor. More usually, however, the combustion gases are returned to the interior of the reactor. In the processes of the second and third embodiments this provides a further source of water vapour for reaction step (b). Where the combustion gases are returned to the reactor, in order to avoid build up of nitrogen in the process, it is more typical to utilise pure oxygen, rather than air, for the combustion step. Advantageously, where the gaseous product removed from the process of the invention is combusted for the purpose of generating electricity, some of that electricity may be used for the electrolysis of water to generate oxygen for use in the combustion of the gaseous product(s) of the process. In one form of the process of the third embodiment, a further portion of the first and/or second gaseous product is combusted to provide the heat necessary to sustain the first elevated temperature for the pyrolysis step, step (a).

In one form of the processes of the invention, flue gases may be supplied to the pyrolysis zone or the reaction zone, or both, for remediation. The flue gas may derive, for example, from combustion of a fossil fuel such as coal, coke, fuel oil or natural gas in a boiler. Especially when the fossil fuel is coal, coke or fuel oil, the flue gas typically contains carbon-containing particulates, which can be removed by passage of the flue gas through a process in accordance with the present invention.

In the process of the first embodiment, the combustible gaseous product is burnt to generate heat and combustion products. Similarly, in the process of the second embodiment the part of the second combustible gaseous product which is not burnt to provide the heat necessary to maintain the temperature of the pyrolysis zone and/or the reaction zone is burnt to generate heat and combustion products. The heat generated from these steps may be recovered and utilised in any desired manner, but typically it is utilised to raise steam for electricity generation. The combustion products are returned to the pyrolysis zone in these embodiments of the invention. The combustible gaseous products may be burnt in air, whereupon a bleed of vapour from the system will be necessary to avoid buildup of nitrogen. However, more typically the gaseous fuel is burnt using pure oxygen. In that case, no buildup of gases occurs in the system, and no gaseous effluent is produced.

When flue gas is supplied to the process of the second embodiment, similarly, a bleed of gases will be required to prevent buildup of nitrogen. Typically this will occur by removal of a part of the combustion product produced in step (e), which, apart from water vapour and possibly nitrogen, contains carbon dioxide which may be recovered for commercial use by standard methods.

Buildup of carbon monoxide and carbon dioxide in the system during continuous operation of the process of the first or second embodiments, if there is no bleed of gases from the system, tends to be inhibited by reaction (3) represented above, which is driven to the left by a tendency of carbon monoxide to accumulate, and to the right by a tendency of carbon dioxide to accumulate. Thus, under steady continuous operation conditions the carbon monoxide and carbon dioxide concentrations reach steady levels (given a constant rate of feeding carbon in the carbon-containing material) and substantially all of the carbon which enters the reactor leaves it as elemental carbon (soot) which is removed from the reactor with ash from the carbon-containing material. It will be appreciated that under these conditions the carbon-containing material must contain at least hydrogen (in chemically bound form) in addition to carbon, and the energy recovered from the process derives substantially from the hydrogen which is present in the material.

It will be appreciated that once the process of the invention has been initiated, it may be operated so as to be essentially self-sustaining by feeding to the reactor continuously or batch-wise additional carbon-containing material and periodically removing from the reactor ash or other inert materials. Carbon may also be removed from the reactor with the ash in some embodiments of the invention. If necessary, the carbon content of the carbon-containing material may be adjusted by blending different materials of different carbon contents so as to maintain a substantially constant supply of carbon to the reactor. Typically, the carbon content of the carbon-containing material is at least about 6 % by weight, based on the total weight of the carbon containing material, and the moisture content is typically not more than about 94 % by weight on the same basis, in order for the process of the invention to be self-sustaining.

Advantageously, when the combustible gaseous product produced by the process of the invention is burnt to raise steam (and especially when it is burnt in oxygen rather than air), the combustion gases may be recycled to the reactor in the pyrolysis zone and/or the reaction zone. This results in an essentially closed gas circulation system from which essentially no gaseous effluent is produced.

At start up, an external source of heat is required in order to elevate the pyrolysis zone to the elevated temperature of the pyrolysis reaction, and to elevate the reaction zone, when

present, to the second elevated temperature. Such an external source of heat may be any convenient source, but is typically a combustible gas or oil.

A reactor vessel for use with a process of the present invention may conveniently be a twin-bell reactor of the type typically used in blast furnaces. This type of reactor includes two chambers, one above the other, the upper of which is a hopper for holding a quantity of carbon-containing material, and the other chamber is a reactor chamber. The hopper is separated from the reactor by a relatively narrow neck which is capable of being closed by a bell-shaped valve. Similarly, the hopper is closeable at its upper end by a similar bell-shaped valve. In operation, the hopper compartment is charged with the lower bell valve in the closed position and the upper one in the open position, whereafter the upper bell is closed and the lower one opened so as to cause the hopper contents to discharge into the reactor. The lower bell is then closed while the reactions proceed. In this way, charging of the reactor may be completed without substantial interruption to the reactions taking place and without the admission of unlimited quantities of air. The hopper vessel may be purged of air before it is discharged into the reactor, if so desired. Typically, purging of air is achieved using steam or carbon dioxide, more usually steam. The reactor vessel may conveniently be provided with a suitable bottom valve for removal of ash periodically.

Conveniently, any unconverted organic materials present in the ash discharged from the reactor may be separated by discharging the ash into water, whereby organic-containing materials tend to float and may be skimmed off and returned to the reactor. Typically, at least a part of the ash removed from the reactor is returned to the pyrolysis zone for mixing with the carbon-containing material, to increase the porosity of the solid materials in the pyrolysis zone and/or the reaction zone.

Figure 1 is a schematic representation of a system for recovery of energy from waste materials utilising a process in accordance with the third embodiment of the present invention. Referring to Figure 1, the system includes reactor 100 which is charged with waste materials 105 in an upper part of the reactor. Below waste materials 105 is pyrolysis zone 110 in which waste materials 105 are converted to carbon-enriched materials. Beneath pyrolysis zone 110 is reaction zone 120 in which the carbon-enriched materials react with water vapour to produce hydrogen and oxides of carbon. Zone 130 is an ash zone, from which ash may be removed into ash receiver 135. Gas off-take 133 is provided to reactor 100, for transferring gases from reactor 100 to boiler 140 for recovery of heat contained in the gases, and thence to gas cooler 150 via air/oxygen preheater 145. Gas cooler 150 is connected to gas storage vessel(s) 160, which is equipped with water off-take 165. The gas outlet of preheater 145 is also connected to burners 170, 171.

In use, reactor 100 is charged with waste materials 105 near its top which pass through pyrolysis zone 110 and reaction zone 120 into ash zone 130 prior to removal from the reactor 100 into ash receptacle 135. That is, as ash is removed from reactor 100, successive charges of waste material 105 move down reactor 100 through zones 110, 120 and 130.

5 Gaseous products 115 of pyrolysis move downwards through reactor 100 into reaction zone 120 where carbon present in carbon-enriched material produced in pyrolysis zone 110 reacts with water vapour generated in that zone or introduced into it, to produce a gaseous product 125 enriched in hydrogen and oxides of carbon which passes out of reactor 100 through gas collection port 133. Waste heat present in gaseous product 125 is recovered in boiler 140
10 from which the gaseous stream passes into preheater 145, gas cooler 150 and then into gas storage vessel 160. In preheater 145, oxygen or air are preheated before being fed to burners 170,171. A portion of gas exiting preheater 145 is passed to burners 170, 171 where the gas is combusted and the generated heat and combustion products are directed to pyrolysis zone 110 and reaction zone 120 of reactor 100 so as to sustain the desired
15 temperatures in those zones. In gas cooler 150, water and other condensibles 155 are removed from the gaseous stream exiting preheater 145. Organic condensables may be separated from water in stream 155 and returned to reactor 100. Gas from gas storage vessel 160 typically predominantly contains carbon monoxide, hydrogen and gaseous organics, and may be removed from storage vessel(s) 160 for combustion and energy
20 recovery.

Figure 2 is a schematic representation of a system for recovery of energy from waste materials utilising a process in accordance with the second embodiment of the present invention. The system illustrated in Figure 2 includes all of the components of the system illustrated in Figure 1 and additionally includes high pressure boiler 180 connected to gas
25 storage vessel(s) 160 and provided with preheated air or oxygen 146 from preheater 145. Exhaust line 185 from high pressure boiler is connected to reactor 100 and is equipped with valve 188, and is also connected via line 187 to gas cooler 190. Line 187 is equipped with valve 189. Gas cooler 190 is connected to carbon dioxide storage 195.

In use, the system illustrated in Figure 2 is operated in the same way as the system
30 illustrated in Figure 1, as described above, except that gas stored in gas storage vessel(s) is not removed for combustion but is sent to high pressure boiler 180 for combustion. Exhaust from boiler 180 typically contains predominantly carbon dioxide and water vapour and is normally returned via line 185 to reactor 100. That is, normally valve 188 is open and valve 189 is closed. If it is desired to remove carbon dioxide from the system, valve 188 may be

closed and valve 189 opened, to direct exhaust from boiler 188 to gas cooler 190 and thence to carbon dioxide storage 195.

Figure 3 is a diagram of a suitable reactor for carrying out a process in accordance with the invention. As seen in Figure 3, reactor 200 includes hopper 210 and reaction chamber 220 below hopper 210. Hopper 210 and reaction chamber 220 are separated by neck region 215 which is closeable by first bell valve 240. Second bell valve 230 permits the upper end of hopper 210 to be closed to the atmosphere. Above second bell valve 230 is charging port 250 for charging solid materials into hopper 210. Hopper 210 is equipped with steam inlet 212 and steam outlet 216, which are fitted with isolation valves 213, 217 respectively.

Reaction chamber 220 is surrounded in its upper portion by firebox 285 equipped with vents 288 for admission of combustion gases from firebox 285 into reaction chamber 220. Reaction chamber 220 is also equipped with ash removal valve 275, gas offtake manifold 293 and gas supply manifold 290 which is connected via gas return 295 to an upper portion of reaction chamber 220.

During continuous operation of reactor 200, first bell valve 240 is normally in the closed position and second bell valve 230 is moved to the open position for charging carbon-containing material 245 into hopper 210 through charging port 250. When this charging step has been completed, second bell valve 230 is moved to the closed position and steam is passed through hopper 210 from steam inlet 212 to steam outlet 216 by opening valves 213, 216, for a time sufficient to purge substantially all of the air from hopper 210. Valves 213, 216 are then closed and first bell valve 240 is opened to permit carbon-containing material 245 to fall into reaction chamber 220. Materials in reaction chamber 220 occupy a pyrolysis zone 250 above reaction zone 260 and ash zone 270. In pyrolysis zone 250 coking or charring of carbon-containing material 245 occurs at the elevated temperature maintained in pyrolysis zone 250 owing to heating of reaction chamber 220 from firebox 285. As additional carbon-containing material 245 is charged into reaction chamber 220 and ash is removed from ash zone 270, material in pyrolysis zone 250 progresses through reactor into reaction zone 260. In reaction zone 260, carbon-enriched material from carbon-containing material 245 reacts with steam generated in pyrolysis zone 250 or present in gases introduced into reaction chamber 220 (for example from firebox 285 via vents 288 or through gas return 295) and produces hydrogen and mixed oxides of carbon. These gases are removed into gas off take manifold 293. Some gases in gas off-take manifold 293 are returned to firebox 285 (connection not shown) or returned to gas supply manifold 290 and thence via gas return 295 to reaction chamber 220. However, the

majority of gases are taken off for combustion and recovery of useful energy therefrom. With further charges of carbon-containing material into reaction chamber 220 and progressive removal of ash 270 via ash removal valve 275, material in reaction zone 260 eventually reaches ash zone 270 and is ultimately removed from reactor 200.

5 Since the processes of the first and second embodiments of the invention may be operated as essentially a closed system, or at least one in which the quantity of gaseous effluent is substantially decreased compared to processes which rely on total combustion of organic materials in waste, they are processes with little or no adverse impact on the environment. Although a process in accordance with the third embodiment of the invention
10 will at least release carbon dioxide to the atmosphere, it provides a process whereby useful energy can be recovered from waste materials with a net reduction in the volume and other problems associated with disposal of the waste. Other major byproducts of the process are water and ash, which may be utilised as a soil substitute or soil conditioner. The other major by-product of the process, namely water, is in increasingly short supply in many parts
15 of the world, and the process of the invention provides a new source of water which may be used, for instance, for irrigation or in domestic water supply (after appropriate treatment).

Example

The following is a description of laboratory scale trials of a process in accordance with the invention.

20 APPARATUS

The reactor was constructed as in Figure 4 with schedule 40 pipe and 8mm plate. Legs, bracing and footings were constructed from 3 x 3 x 0.25-inch (75 x 75 x 6.4mm) angle section. All flanges and blanks were ANSI 300lb (2070kPa) fittings. The lid to the reactor, a 24" (600mm) flange & blank (ANSI-300lb (2070kPa)) was fitted with pressure
25 relief valve set at 100 psi (689kPa) and pressure gauge. It was also fitted with a 2.5" (64mm) flanged stub and ball valve to allow access of a steel, graduated dipstick.

Four gas ring burners were installed at 90-degree rotation intervals at the 0.25m elevation from the bottom of the firebox and with the tip of the flame impinging on the heating surface. Four more were placed at 45 degree rotation from the first set and again 90
30 degrees rotation between the burners at the 1.25m elevation. Each burner ring was individually equipped with an isolation valve. 0.5" (12mm) sockets at 4 locations served as inlets for compressed air.

The complete outside surface of the apparatus was insulated with asbestos cement fibre and coated with phenolic resin. The internal surface of the external walls of the
35 firebox was coated with vermiculite refractory paste.

This design results in a 12" (300mm) thick waste section to be heated by the flame on one side and hot exhaust and volatile gases on the other.

The combustion gases pass from the firebox into the reaction chamber through 6" (150mm) holes where and mix with the volatile gasses pass down the centre tube. These gases then exit the centre tube and migrate back up through the carbonaceous residue in the annular space between the firebox and the central tube to exit to a compressor by way of 4 x 6" (150mm) outlets and manifold fitted with a rupture disc.

From the compressor, the gas/vapour passes through a water-cooled heat exchanger and into 1 of 2 parallel piped storage vessels, as illustrated schematically in Figure 5. The storage vessel design include a steam trap, fitted with a "goose neck" water draw. Further it was fitted with 100-psi (689kPa) pressure gauge, pressure relief valve, gas purge and product effluent valves. The effluent valves were by way of a manifold joined together and then connected to a second compressor by way of a pipe section containing a rupture disc. The second compressor was then connected to the burner feed manifold.

A bottled LPG manifold was set up as the initial heat source was also connected to the burner feed manifold.

CHARGE VOLUME CALCULATION.

Volume of waste zone

Outer diameter	0.6	m
Inner diameter	0.3	m
Length	2	m
Volume annular space	0.424	m ³

Volume of carbon zone

Outer diameter	0.6	m
Inner diameter	0.3	m
Length	1	m
Volume annular space	0.212	m ³

Volume of ash zone

Cone volume	0.038	m ³
Height	0.4	m
Diameter	0.6	m

INITIAL CHARGE VOLUME 0.674 m³

DESIGN CHARGE/HR 0.4 m³

DESTRUCTION – PRINCIPLES INVOLVED.

On filling the reactor the waste feeds into the annular space between the firebox and the central down comer. On entrance to this space the waste is in the coking (pyrolysis) stage.

Stage I - THE COKING STAGE

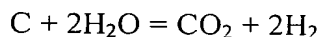
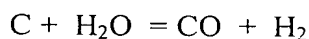
The coking stage of the process takes place in the top 2m of the reactor where complex organic compounds are broken down by heating them to temperatures above 400°F (205°C) to produce carbon or char, low molecular weight organics (which volatilise), water (which is converted to steam) and silica and inorganic ash. All except the carbon, silica and inorganic ash exit the reaction in the gas phase. The residual solid is coke or char.

The gas and vapours pass down through the centre co-axial pipe (the path of least resistance) to exit and migrate back up through the coke residue where they take part in the Stage II reactions in which water vapour is converted to water gas.

Stage II – WATER GAS PRODUCTION

WATER GAS (or Blue gas) is produced when steam is blown through an incandescent bed of Carbon.

The gas production reactions are primarily:



These reactions occur when the water from the waste (steam) is passed back through the residual coke or char in the bottom 1-m of the reactor. Both of these reactions are endothermic. Therefore, the temperature of the bed of carbon through which the steam is blown would be lowered quickly to a point where no reaction would occur, if no heat were added to the system.

OPERATION

Initial Charge

1. The system was constructed and assembled as in Figures 3 and 4.
2. The gas extraction and feed lines to the system were hydraulically tested.
3. The reactor was filled with coconut shells (0.6m³) and the reactor was sealed.
4. The system was purged with steam.

5. The cooling water system was started and valves in the gas extraction line to tank 1 were opened.
6. The LPG gas flow and air compressors were started and the gas was ignited.
7. When the reactor pressure had risen to 60-psi the exhaust compressor was started with feed to storage tank 1.
8. When the reactor pressure fell-away gas to the burners was stopped.
9. The dipstick ball valve was opened and the system shut down.
10. The reactor was dipped. Steps 3 and 5-9 (but not step 4) were repeated if the bed depth was below 2m from the top close valve.
11. If the bed depth was above 2-m, ash was removed to this level by opening the bottom hatch.

Methods – Testing Procedures

1. Three consecutive charges of 0.4-m^3 of each of the following were sequentially added to the reactor.
 - Municipal Garbage
 - Rubber tyres
 - Wet Bagasse
 - Saw Dust
 - Oil Sludge
2. The reactor was filled with the respective charge (0.4m^3) and the reactor was sealed.
3. The cooling water system was started and the valves in the gas extraction line to tank 1 were opened.
4. The gas flow was started from the previous gas storage tank and the air compressors and the gas was ignited. If no gas was available the LPG gas valve was opened.
5. When the reactor pressure reached 60 psi (about 415 kPa), the exhaust compressor was opened with feed to the current storage tank.
6. When the reactor pressure fell away the gas to the burners was stopped, the dipstick ball valve was opened and the system shut down.
7. The reactor was dipped.
8. Steps 1-7 were repeated for the next charge.

RESULTS

Charge 1-Garbage

depth at end of previous charge

220 cm

Fired by

LPG

	16		
	depth at end of current charge	230 cm	
	residual from this charge	0.1 m	
	volume	0.021214 m ³	
2	<u>Charge 2-Garbage</u>		Produced gas
	depth at end of previous charge	230 cm	
	depth at end of current charge	240 cm	
	residual from this charge	0.1 m	
	Volume	0.021214 m ³	
3	<u>Charge 3-Garbage</u>		Produced gas
	depth at end of previous charge	240 cm	
	depth at end of current charge	255 cm	
	residual from this charge	0.15 m	
	volume	0.031821 m ³	
4	<u>Charge 4- Tyres</u>		Produced gas
	depth at end of previous charge	255 cm	
	depth at end of current charge	300 cm	
	residual from this charge	0.45 m	
	volume	0.095464 m ³	
5	<u>Charge 5- Tyres</u>		LPG
	depth at end of previous charge	300 cm	
	depth at end of current charge	350 cm	
	residual from this charge	0.5 m	
	volume	0.106071 m ³	
			ash removed 200 Litres
			94.27609 cm
6	<u>Charge 6- Tyres</u>		LPG
	initial dip	205 cm	
	depth at end of current charge	260 cm	
	residual from this charge	0.55 m	
	volume	0.116679 m ³	

7 Charge 7 - wet bagasse

LPG

initial dip	260 cm
depth at end of current charge	275 cm
residual from this charge	0.15 m
volume	0.031821 m ³

8 Charge 8 - wet bagasse

Produced gas

initial dip	275 cm
depth at end of current charge	280 cm
residual from this charge	0.05 m
volume	0.010607 m ³

9 Charge 9 - wet bagasse

Produced gas

initial dip	280 cm
depth at end of current charge	295 cm
residual from this charge	0.15 m
volume	0.031821 m ³

10 Charge 10 - saw dust

Produced gas

initial dip	295 cm
depth at end of current charge	310 cm
residual from this charge	0.15 m
Volume	0.031821 m ³

11 Charge 11 - saw dust

Produced gas

initial dip	310 cm
depth at end of current charge	320 cm
residual from this charge	0.1 m
volume	0.021214 m ³

12 Charge 12 - saw dust

Produced gas

initial dip	310 cm
depth at end of current charge	320 cm
residual from this charge	0.1 m
volume	0.021214 m ³

13	<u>Charge 13 - oil sludge</u>	Produced gas
	initial dip	320 cm
	depth at end of current charge	325 cm
	residual from this charge	0.05 m
	volume	0.010607 m ³
14	<u>Charge 14 - oil sludge</u>	Produced gas
	initial dip	325 cm
	depth at end of current charge	340 cm
	residual from this charge	0.15 m
	volume	0.031821 m ³
15	<u>Charge 15 - oil sludge</u>	Produced gas
	initial dip	340 cm
	depth at end of current charge	355 cm
	residual from this charge	0.15 m
	Volume	0.031821 m ³
	residual at end of test	355 cm
		0.75 m ³
	total through put	6.6 m ³
	% ash	11.41
	waste converted to gas	5.8 m ³

The above results indicate that the destruction of rubber tyres does not sustain gas production. This is to be expected given the carbon content and lack of water. It could be expected that if it were mixed with a high water waste it would effect a very good yield of water gas. Whilst not 100% conclusive the subsequent gas production is a strong indication of this being the case.

Given the results of the tyre destruction it was decided to continue tyre destruction to assess the gas production. It was found that a further 5 charges of tyres was possible before the produced gas was exhausted and the system required the supplement of LPG.

The above results indicate that there is excess gas production from the destruction of most wastes, compared to the quantity of gas which is required for the destruction of the waste. In particular municipal garbage could be effectively disposed in this manner.

The claims defining the invention are as follows:

1. A process for generating heat from a carbon-containing material which includes the steps of:

(a) pyrolysing said material in a pyrolysis zone of a reactor at an elevated temperature to produce a carbon-enriched solid and a combustible gaseous product;

(b) burning a first part of said gaseous product to produce a first gaseous combustion product and to heat said pyrolysis zone so as to maintain said elevated temperature;

(c) removing a second part of said combustible gaseous product from said reactor;

(d) burning said second part of said combustible gaseous product to generate heat and produce second gaseous combustion products; and

(e) returning said first and second gaseous combustion products to said pyrolysis zone.

2. A process for generating heat from a carbon-containing material which includes the steps of:

(a) pyrolysing said material in a pyrolysis zone at a first elevated temperature to produce a carbon-enriched solid and a first combustible gaseous product;

(a') transferring said carbon-enriched solid and said first combustible gaseous product to a reaction zone;

(b) reacting said carbon-enriched solid with water vapour in said reaction zone at a second elevated temperature to produce a second combustible gaseous product containing hydrogen gas and carbon monoxide;

(c) burning a first part of said second combustible gaseous product to produce first gaseous combustion products and to heat at least said reaction zone so as to maintain said second elevated temperature;

(d) removing a second part of said second combustible gaseous product from said reaction zone;

(e) burning said second part of said second combustible gaseous product to generate heat and second gaseous combustion products; and

(f) returning said first and second gaseous combustion products to said pyrolysis zone.

3. A process for converting a carbon-containing material to a combustible gaseous fuel which includes the steps of:

(a) pyrolysing said material in a pyrolysis zone at a first elevated temperature to produce a carbon-enriched solid and a first gaseous product;

(b) reacting said carbon-enriched solid with water vapour in a second reaction zone at a second elevated temperature to produce a second gaseous product containing hydrogen gas and carbon monoxide;

(c) burning a first part of (i) said first gaseous product, (ii) said second gaseous product or (iii) a mixture thereof so as to heat at least said reaction zone and maintain said second elevated temperature; and

(d) removing the remainder of said first and second gaseous products as said combustible gaseous fuel.

4. A process according to claim 3 wherein step (c) consists of burning a first part of said second gaseous product.

5. A process according to any one of claims 1-4 wherein said carbon-containing material includes municipal waste, sewage or a mixture thereof.

DATED this Twenty-ninth Day of September, 1999

World Oasis Australia Pty Ltd

Patent Attorneys for the Applicant

SPRUSON & FERGUSON

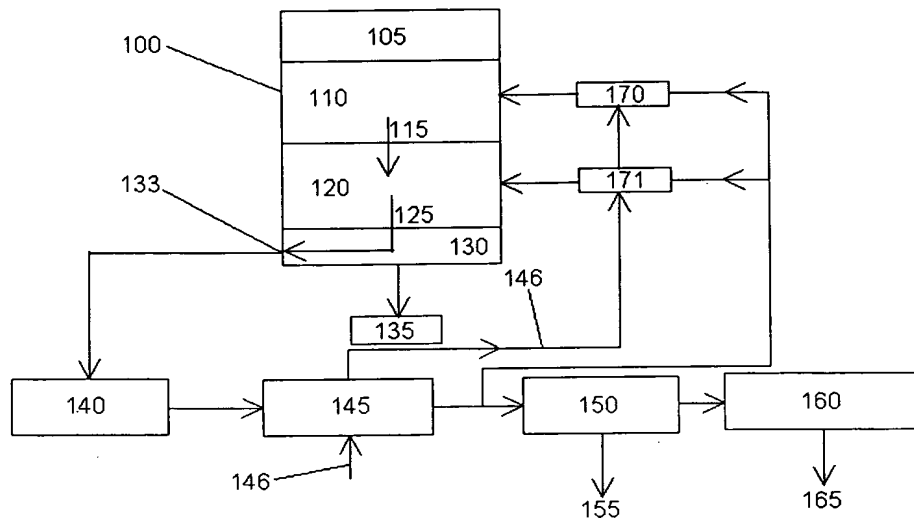
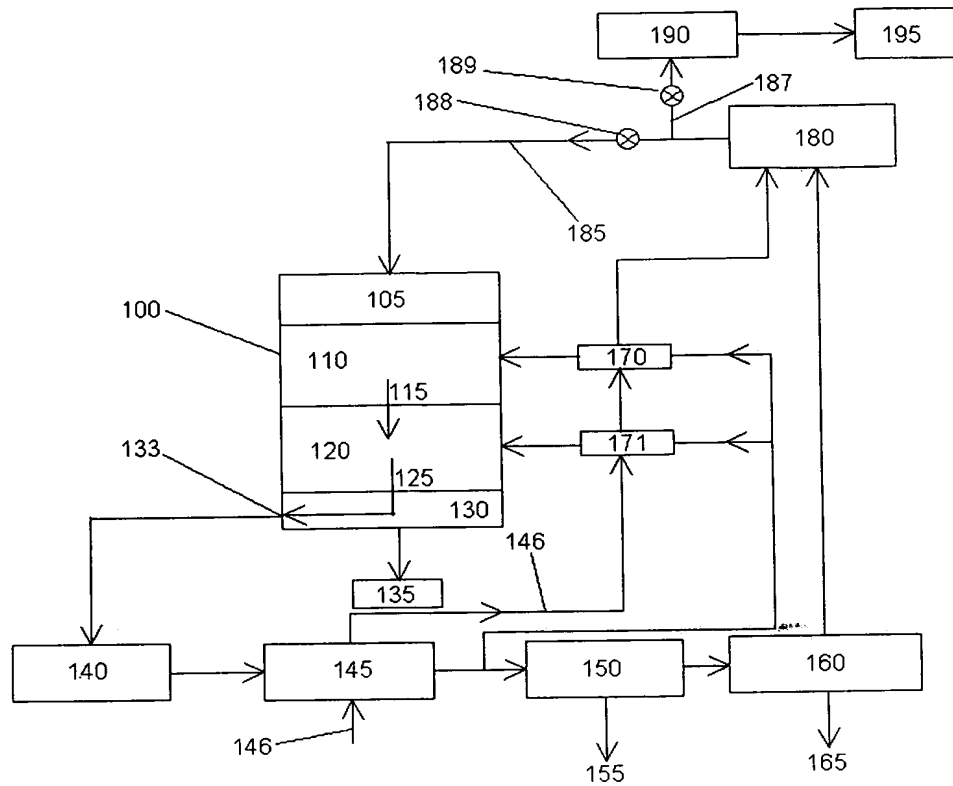


FIGURE 1

**FIGURE 2**

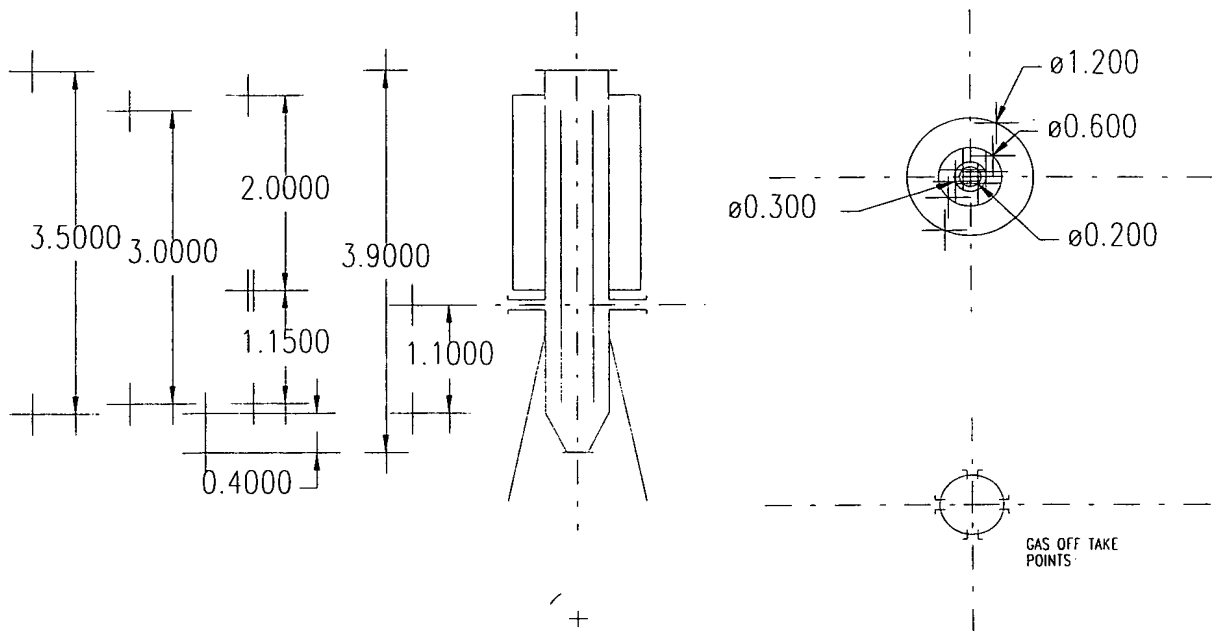


FIGURE 4

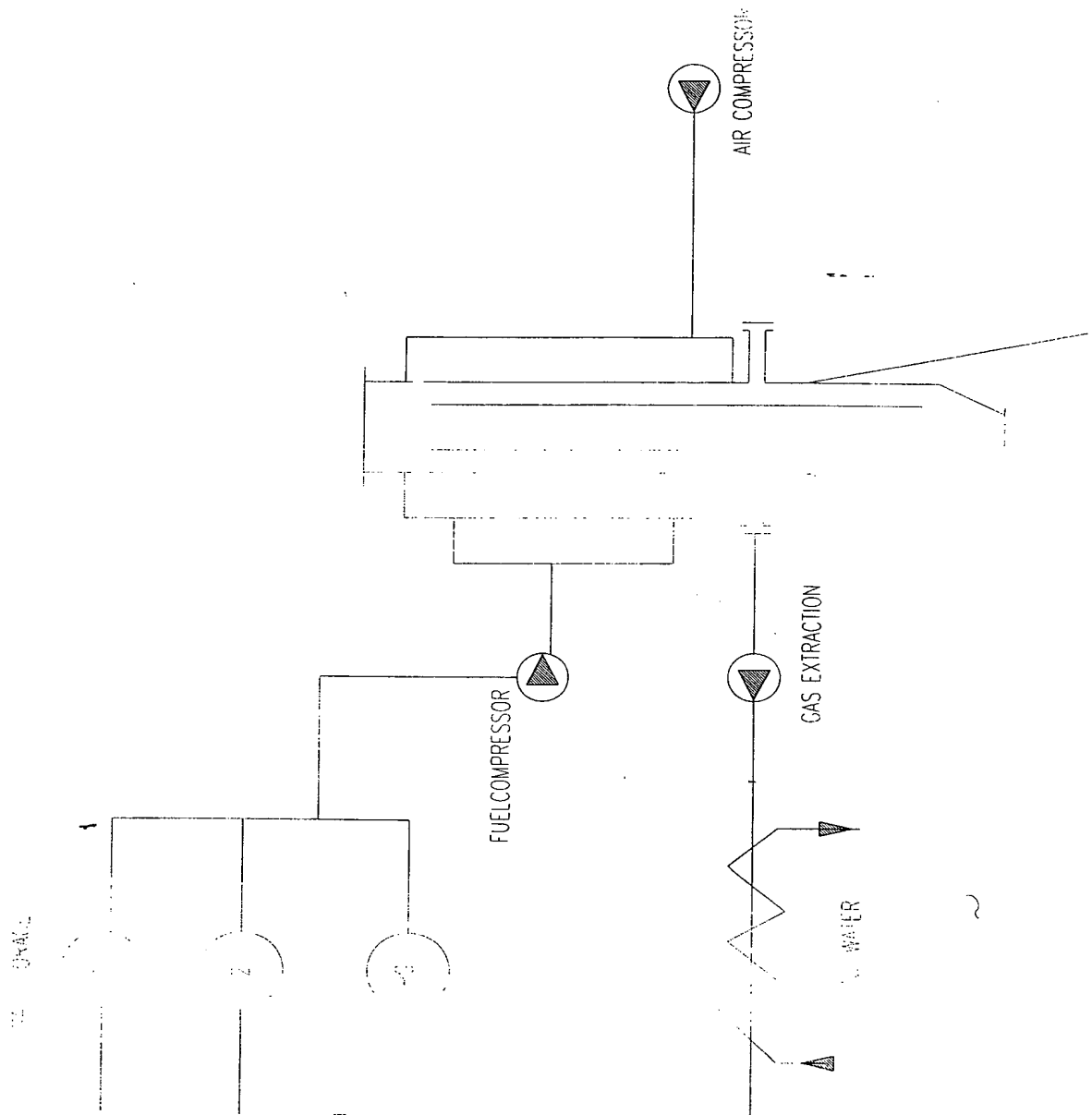


FIGURE 5

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